



ERTMS (European Railway Trains Management System) will be submitted to a major update to accelerate towards fully digitized and automated mainline rail operations in Europe, paving the way for a sustainable traffic system throughout the continent.

In this context, ERTMS needs to move away from trackside-based train detection systems to onboard safe navigation systems using multi sensor fusion in an improved Localization On-Board (LOC-OB) System. Increasing the line capacity by headways reduction between trains thanks to the “moving-block” concept, while reducing expenditure for rail infrastructure rollout, all thanks to this new LOC-OB System for ERTMS, can help reduce greenhouse gas emissions, help digitalize the railways, and accelerate the adoption of sustainable and smart mobility solutions that revolve around rail.

LOC4RAIL is a 4-year project - from mid-2019 up to mid-2023 – whose main objective was to prototype an innovative solution answering to the requirements of such LOC-OB system, providing an “all-in-one solution” more accurate and more reliable in position, speed, and attitudes in line with the safety targets required by the safe train localization, and to evaluate the performance of the LOC4RAIL solution based on a large amount of real data collected onboard different types of train (urban, regional, high-speed) in many different weather conditions (heat/cold, dry/wet, ionospheric-tropospheric conditions...), or environmental conditions (forests, mountains, tunnels, buildings, stations in urban area, etc.).

The partners of LOC4RAIL are leaders in their domains as described below:

- Exail (Formerly iXblue), manager of this project, is a worldwide reference in inertial components (Fiber Optic Gyroscopes & Micro Electro Mechanical Accelerometers manufacturer) and in inertial navigation systems. Realized the demonstrator rack, supported installation onboard with SNCF, collected mass data on server, generated massive reference map, in charge of inertial navigation block (INS-R), performance and supervisor-vote block and definition/implementation in LOC4RAIL system architecture. During this program, Exail Won two ERCI Awards in railway innovative (French and European@2022 Berlin Innotrans Exhibition) and edited two major patents in railway navigation.
- SNCF, the French public railway company, contributed its experience in rail transport management and its expertise in rail environment and infrastructure. SNCF was responsible for establishing the functional requirements, defining the use cases, and identifying the interface constraints with the existing systems. It has also made trains available (TGV, RER, TER) for demonstrations. It has contributed to define cartography specifications and led the economic analysis made on localization system.
- CNES, the French Space Agency, has a world-class expertise in satellite navigation, in particular in GNSS "PPP" precision positioning technology. In the framework of LOC4RAIL, CNES has upgraded its PPP positioning solution, from the generation of the PPP orbitography-synchronization corrections to the software used to determine the train's Position/Speed with GNSS measurements. CNES thus provided its partner Geoflex and the LOC4RAIL consortium with the core processing of the GNSS-R subsystem, with a reliable, robust and accurate solution adapted to the railway context. CNES also contributed to the definition of the overall architecture of the LOC4RAIL system and the supervisor-vote block.
- Geoflex is operator of new PPP services based on the CNES patented technology providing precise, safe, available, and resilient positioning everywhere in the world. Geoflex has specified, and then designed, from the



CNES's algorithms, the GNSS-R subsystem from the "Failure Mode and Effect Critical Analysis" and the "Fault Tree Analysis", to obtain an Architecture, both on the server side (PPP correction generation), than in the rover side (PPP correction usage), based on different GNSS-PPP Positioning Engines doing tight hybridizations with independent inertial measurements (motion constraints) and using the cartographic information as location constraints. Geoflex performed all the tests of this subsystem for validation, based on a mass-data analysis.

During this program, Exail racks, that embed inertial navigations systems (INS) based on their Fiber-Optic Gyroscopes (F50), MEMS accelerometers, and a multi-constellations GNSS receiver, has been installed on board of SNCF trains.

More than 300.000 km of rides of GNSS and inertial raw data has been collected during the 2-years test campaigns for a massive performance analysis.



Figure 1 Reference trajectories for TGV, TER and RER rides -2021-2023

The reference trajectories of the global train rides have been generated for LOC4RAIL LOC-OB performance analysis (geographic view as map above).

The innovative LOC4RAIL architecture is composed of two totally independent and technologically heterogenous blocks - INS-R and GNSS-R:

- INS-R (EXAIL) is a GNSS-free block: INS coupling with innovative virtual inertial balises on digital map and a wheel sensor,
- GNSS-R (CNES/Geoflex) is a block made up with GNSS-PPP engine and a speed sensor (IMU).

Hereafter, the final performance LOC4RAIL results in which confidence interval (CI) of each subsystem have been evaluated towards the specified safe requirements (no physical devices required on the track).

Based on a functional safety analysis of each block and of the overall solution, the LOC4RAIL architecture has demonstrated its performance towards the safety performance expectations. Results show that the two embedded technologies answer to the LOC-OB requirements and user needs. The massive data collected and analyzed is considered as a "World Premiere" on safe train localization. The next step is to improve Technological Readiness Level on some functions, to reinforce analysis and architecture and to answer the ERTMS User Group CBA expectation by estimating how architecture is adapted for this new objective



	Error Rate			Availability			3σ Accuracy [m]		
	subsystem requirement from $10^{-6}$ to $10^{-7}$	system requirement from $10^{-12}$ to $10^{-13}$		subsystem requirement > 99,999%	system requirement > 99,998%				
Mass Data Analysis (~50.10 <sup>6</sup> samples)	UC - HIGH-SPEED TGV *	UC – REGIONAL TER	UC – SUBURBAN RER	UC - HIGH-SPEED TGV *	UC – REGIONAL TER	UC – SUBURBAN RER	UC - HIGH-SPEED TGV *	UC – REGIONAL TER	UC – SUBURBAN RER
INS-R	4.00E-07	0.00E+0	9.63E-08	96.260%	99.240%	99.960%	16	7.5	4.7
GNSS-R	3.27E-07	2.51E-06	2.67E-06	94.620%	93.161%	81.781%	1.52	1.18	1.25
Supervisor (6 trajectories)	0.00E+0	0.00E+0	0.00E+0	89.480%	89.560%	81.085%	7.35	4.1	1.95

\* TGV INS-R without wheel sensor

Figure 2 2023 LOC4RAIL architecture performance